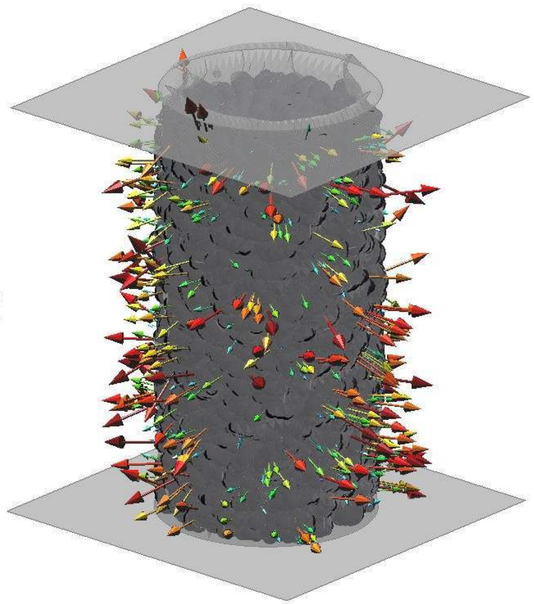
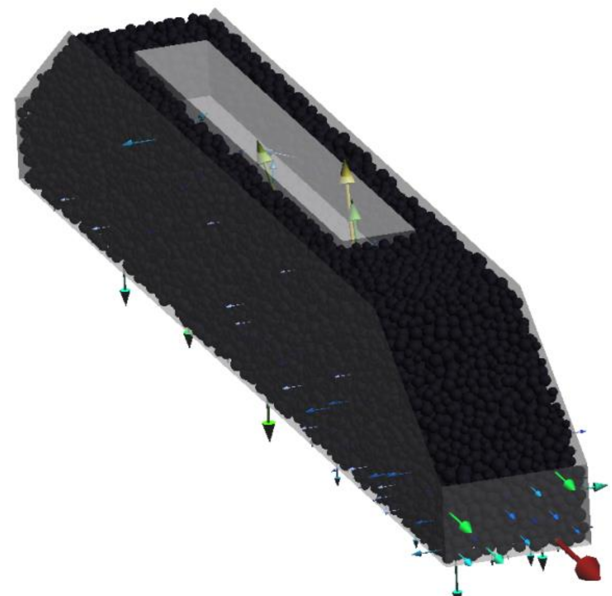
ECCOMAS Thematic Conference
IV International Conference on Particle-Based Methods. Fundamentals and Applications
PARTICLES 2015
28 - 30 September 2015, Barcelona, Spain
IACM Special Interest Conference

Numerical modelling of railway ballast behaviour using de Discrete Element Method (DEM) and spherical particles





Authors: Joaquín Irazábal, Fernando Salazar y Eugenio Oñate

OUTLINE

- Motivation and objectives
- Railway Ballast
- Discrete Element Method (DEM)
- Software
- Ballast representation with spheric particles
- Laboratory tests
- Different particles shape
- Conclusions

MOTIVATION AND OBJECTIVES

Motivation:

- Increasing interest all over the world in high-speed trains

Objectives:

- Study railway ballast properties
- **Develop a numerical tool to reproduce quantitatively the macro-mechanical behaviour of railway ballast using the DEM**
- **Validate the code**

BALAMED
January 2013 – December 2015

GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

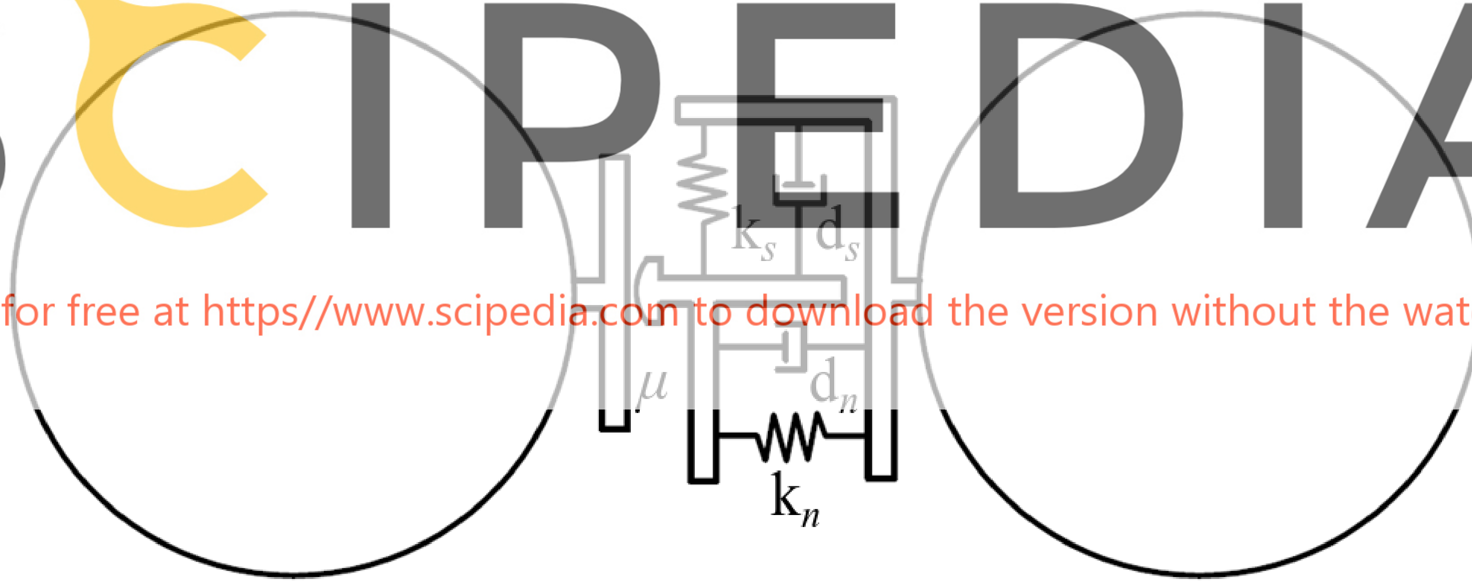
RAILWAY BALLAST

Layer of granular material placed under the sleepers whose roles are: resisting to vertical and horizontal loads and facing climate action

DISCRETE ELEMENT METHOD

Contact constitutive model:

Rigid bodies, deformation concentrated in contact points



$$F = \sum_{c=1}^{N_c} F^c + F^{ext} + F^{damp}$$

$$\begin{cases} m \cdot \ddot{u} = F \\ I \cdot \dot{\omega} = M \end{cases}$$

$$M = \sum_{c=1}^{N_c} (r^c \times F^c + q^c) + M^{ext} + M^{damp}$$

DISCRETE ELEMENT METHOD

Algorithm:

1 • Contact Detection

2 • Forces Evaluation

3 • Integration of Motion

1 • Contact Detection

One Calculation Step

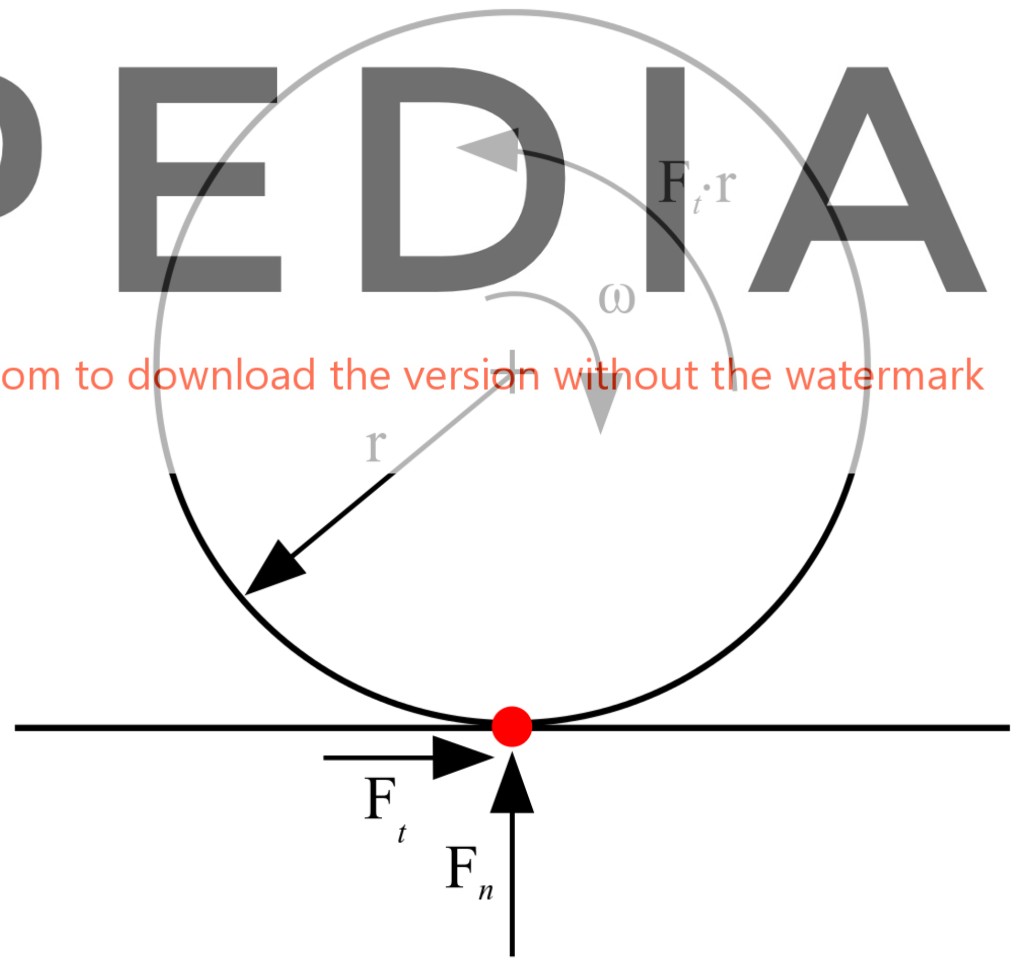
SOFTWARE

http://www.cimne.com/dempack/
http://www.cimne.com/kratos/
http://gid.cimne.upc.es/

BALLAST REPRESENTATION WITH SPHERES

Rolling friction:

Geometrical "property" that consists in imposing a virtual moment opposite to particle rotation and dependent on its size



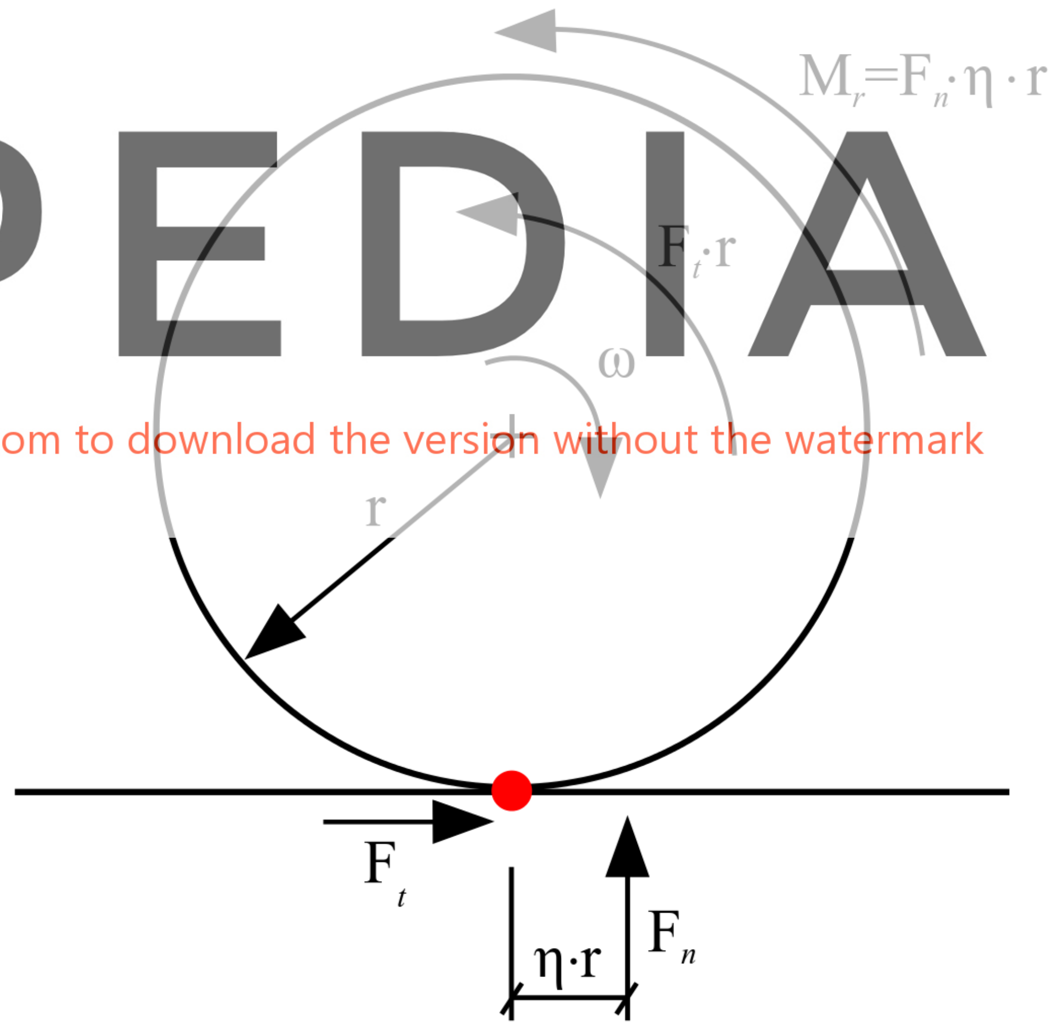
C. M. Wensrich and A. Katterfeld. Rolling friction as a technique for modelling particle shape in DEM. Powder Technology, 217:409–417, February 2012

CIMNE

BALLAST REPRESENTATION WITH SPHERES

Rolling friction:

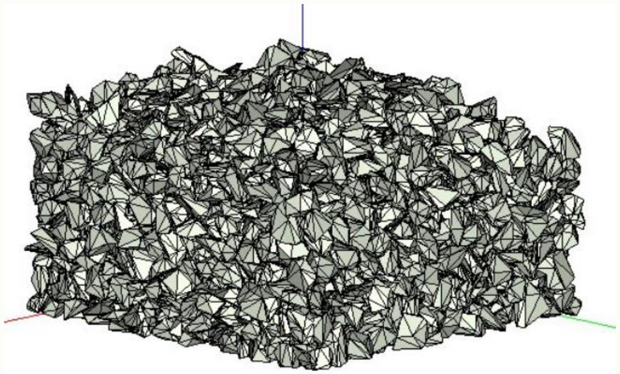
<u>Geometrical "property"</u> that consists in imposing a virtual moment opposite to particle rotation and dependent on its size



C. M. Wensrich and A. Katterfeld. Rolling friction as a technique for modelling particle shape in DEM. *Powder Technology, 217:409–417, February 2012*

TEST RESULTS

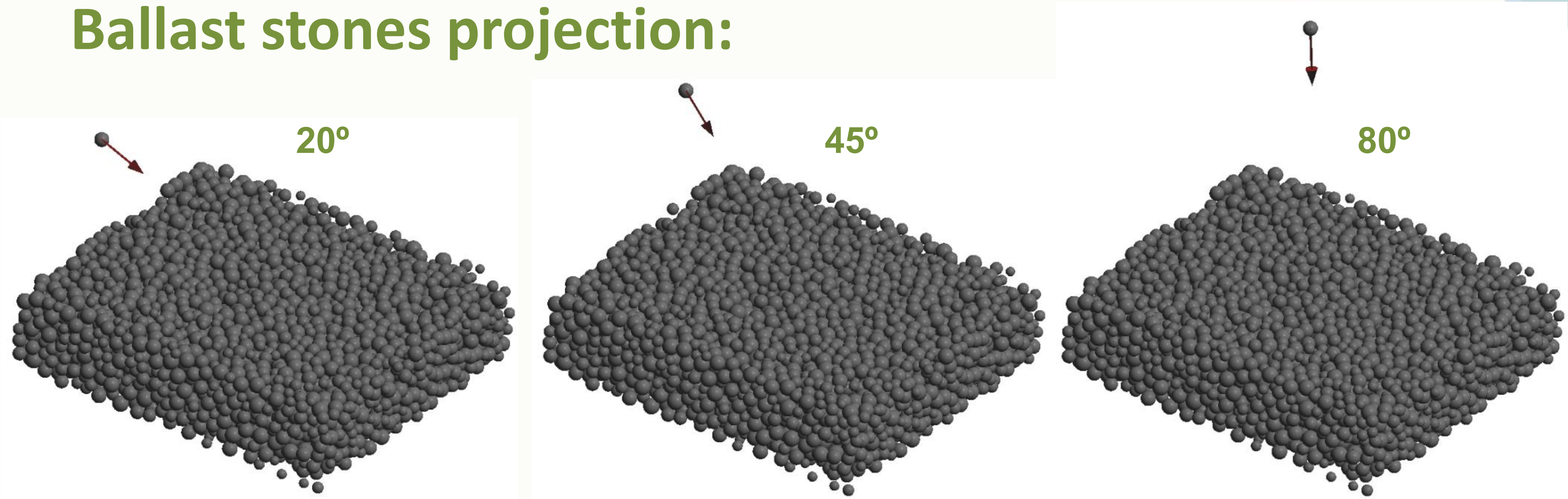
Ballast stones projection:



Kaltenbach, H.J. et al. T. Assessment of the aerodynamic loads on the trackbed causing ballast projection: results from the DEUFRAKO project aerodynamics in open air (AOA). Seul, 2008.

TEST RESULTS

Ballast stones projection:

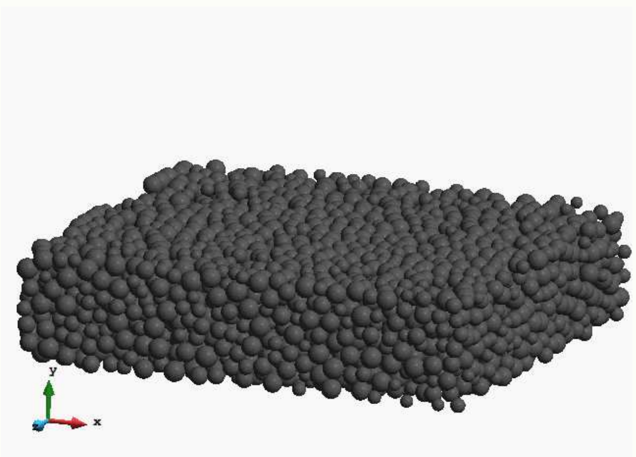


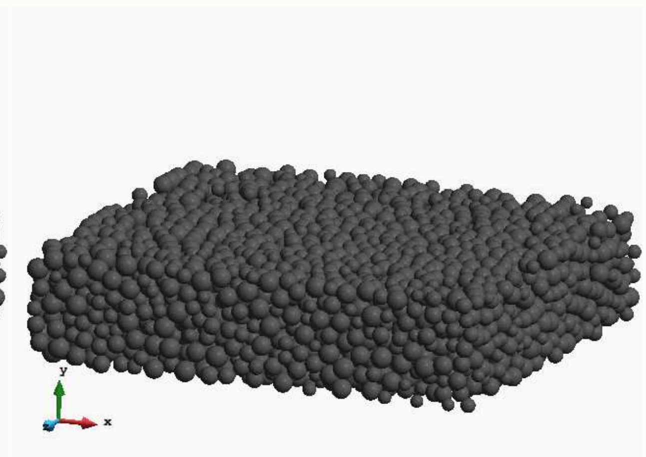
Ballast properties			
Density (kg/m^3)	2700	Friction coeff.	0.6
Young Modulus (Pa)	1.2e8	Restitution coeff.	0.4
Poisson ratio	0.18	Rolling fricition coeff.	0.33
Mean diameter (m)	0.05		
Input parameters			
Projected stone radius (m)			0.05

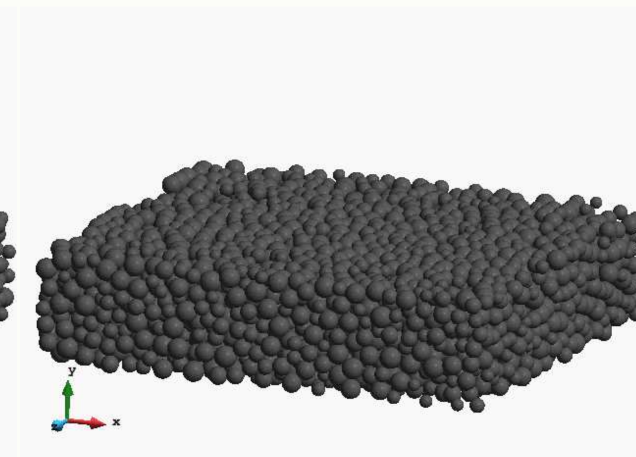
TEST RESULTS

Ballast stones projection:

1000 J





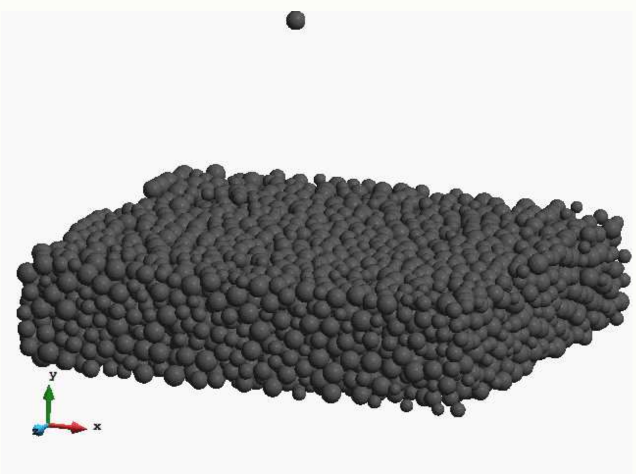


20º **45º** **80º**

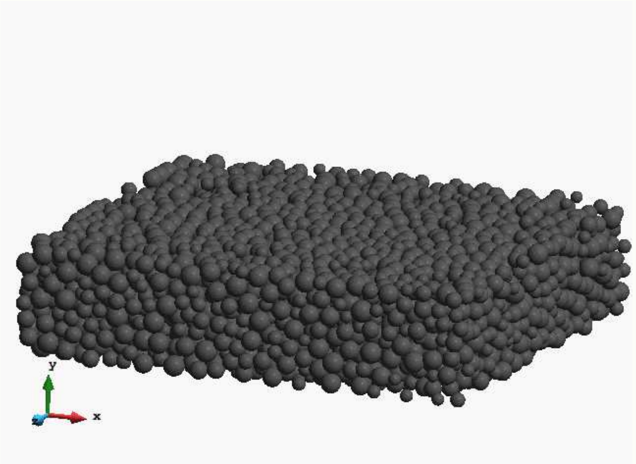
TEST RESULTS

Ballast stones projection:

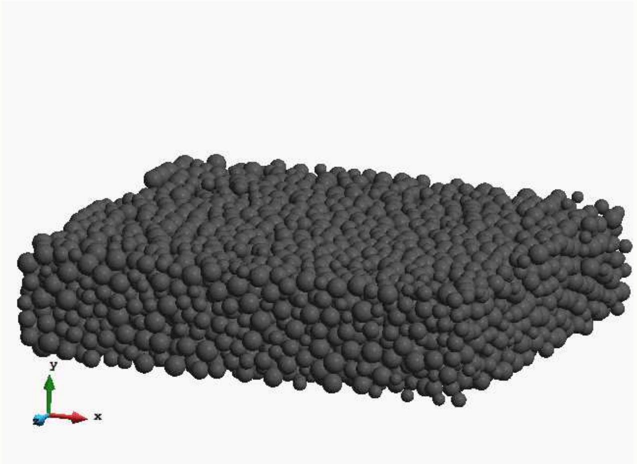
80º



100 J



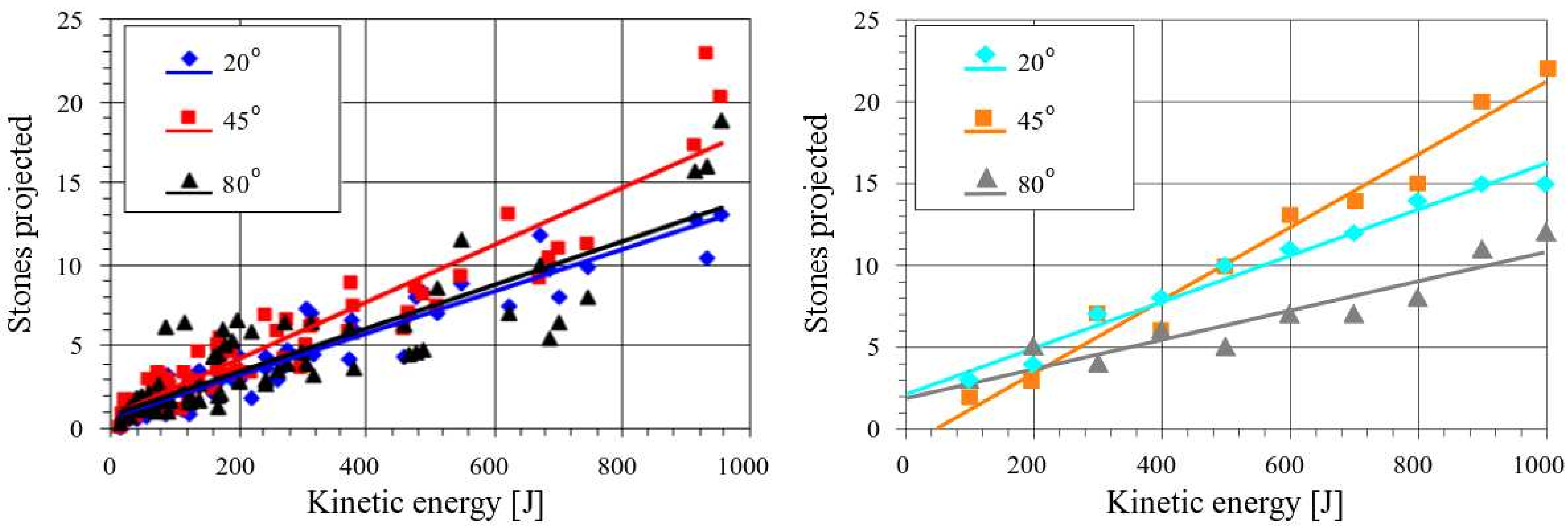
500 J



1000 J

TEST RESULTS

Ballast stones projection:

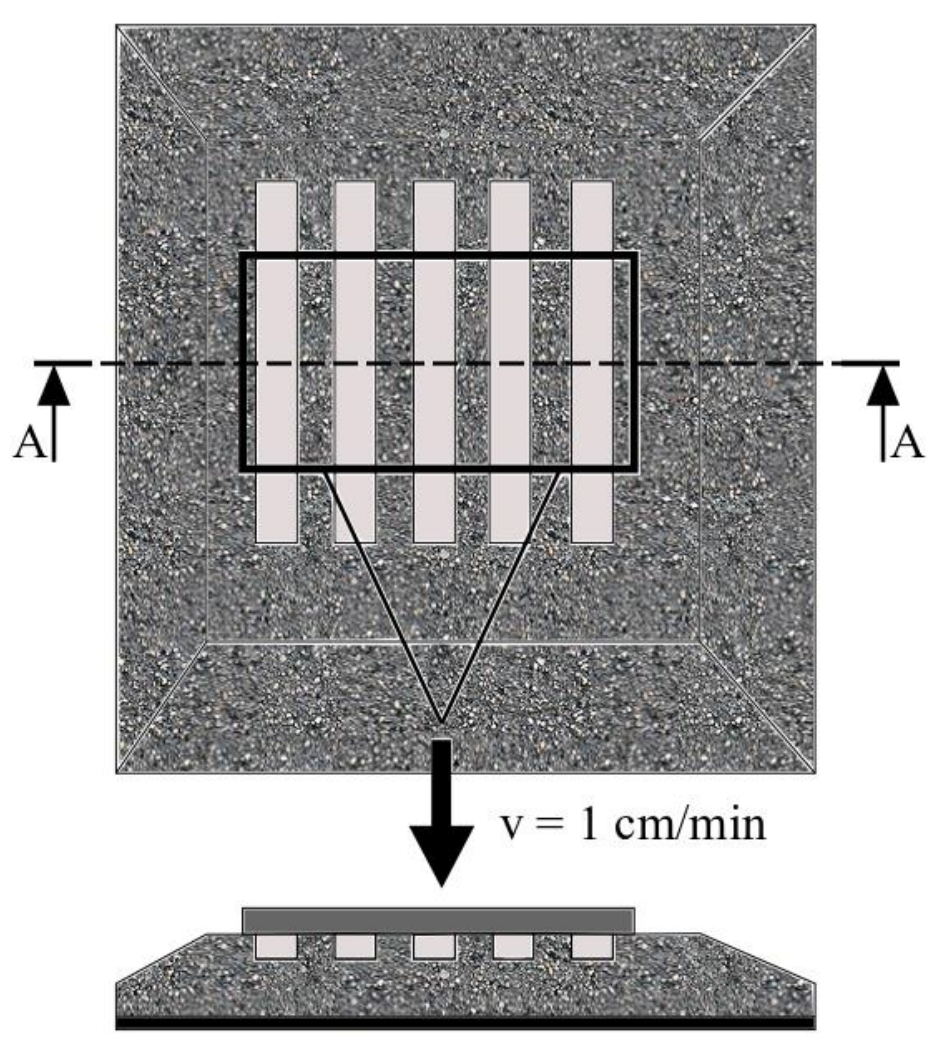


CIMNE

TEST RESULTS

Lateral resistance test:

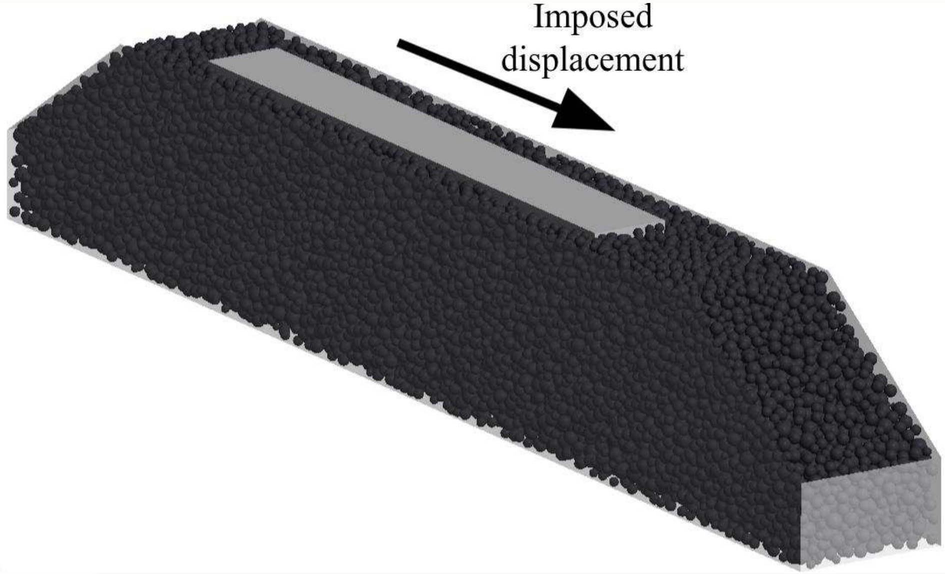
Vertical load= 0 N
Sleepers Velocity = 0.0001667 m/s



Zand and Moraal (1997)
Roads and Railways Research Laboratory
Technical University of Delft

TEST RESULTS

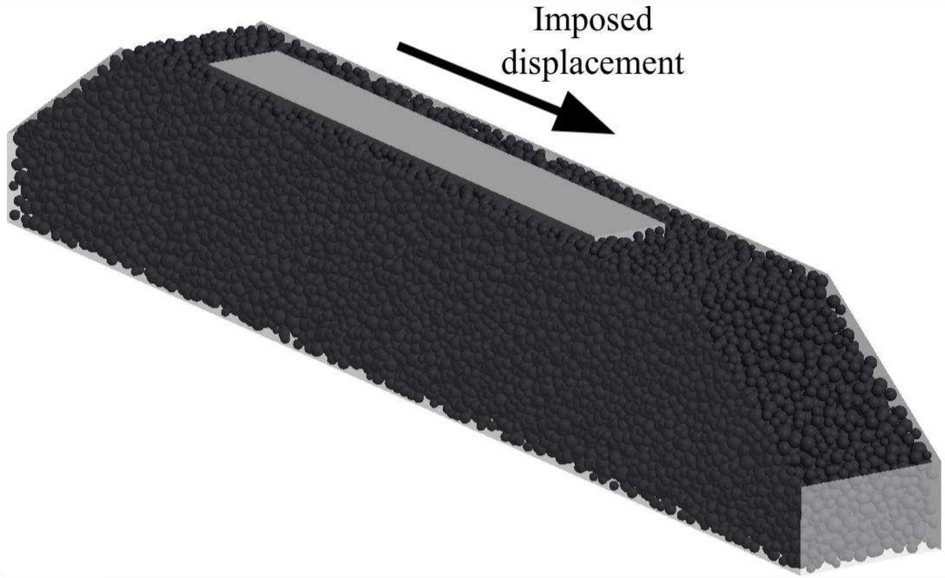
Lateral resistance test:



Ballast properties	
Density (kg/m^3)	2700
Young Modulus (Pa)	5.1e9
Poisson ratio	0.18
Mean diameter (m)	0.05
Friction coeff.	0.6
Friction coeff. ballast/sleeper	0.7
Restitution coeff.	0.4
Rolling fricition coeff.	0.33
Input parameters	
Stabilization time (s)	1.0

TEST RESULTS

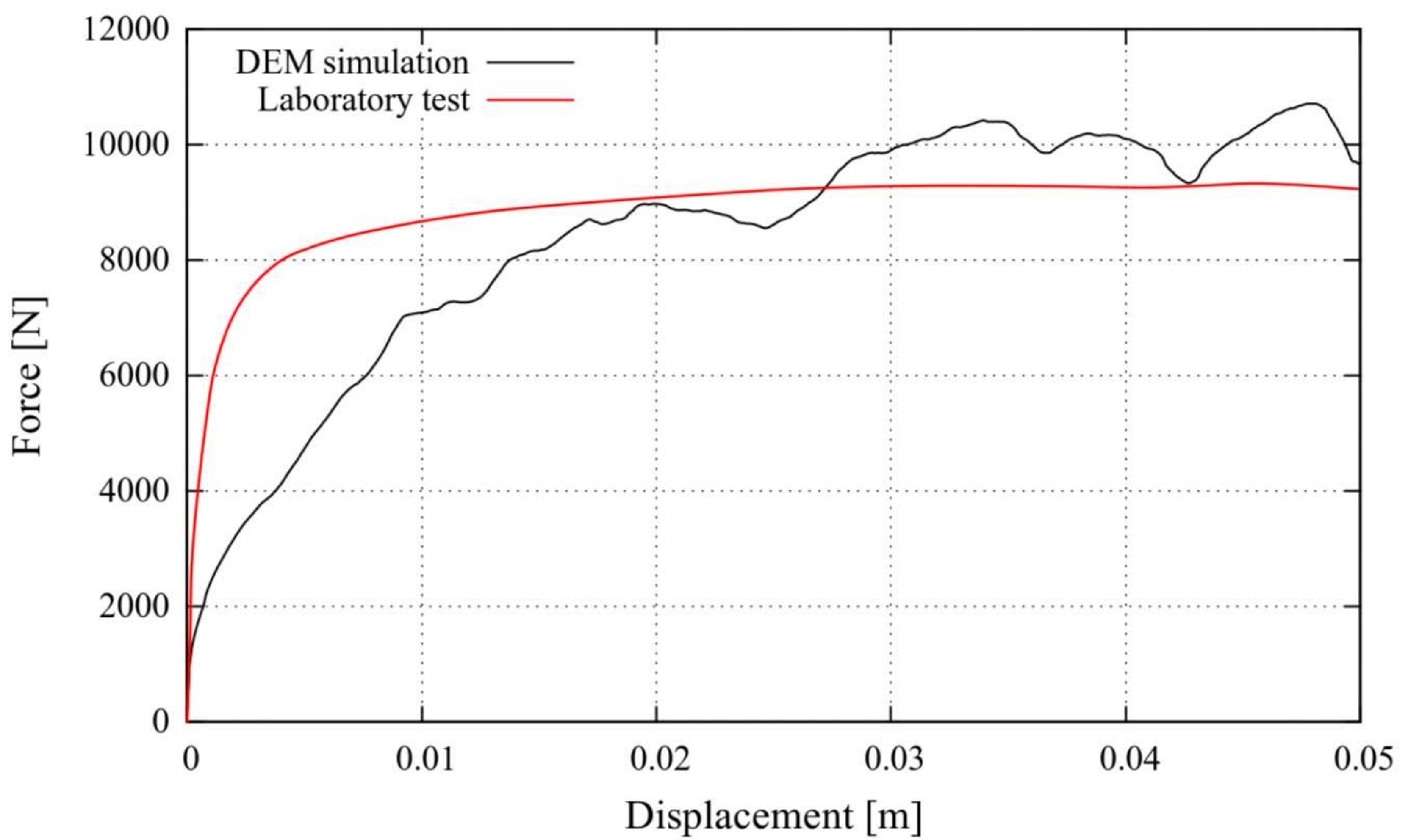
Lateral resistance test:



Ballast properties	
Density (kg/m^3)	2700
Young Modulus (Pa)	5.1e9
Poisson ratio	0.18
Mean diameter (m)	0.05
Friction coeff.	0.6
Friction coeff. ballast/sleeper	0.7
Restitution coeff.	0.4
Rolling fricition coeff.	0.33
Input parameters	
Stabilization time (s)	1.0

TEST RESULTS

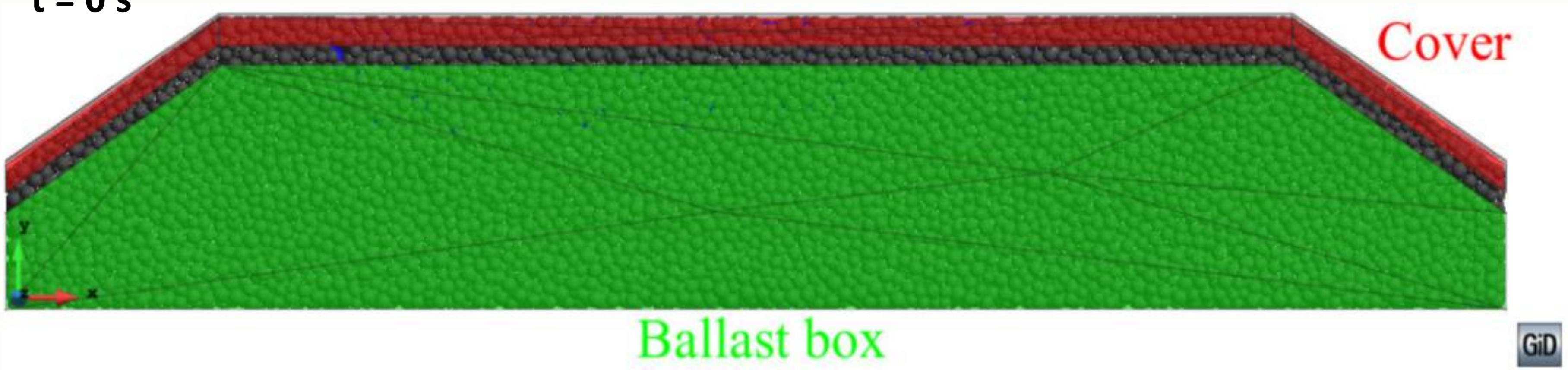
Lateral resistance test:



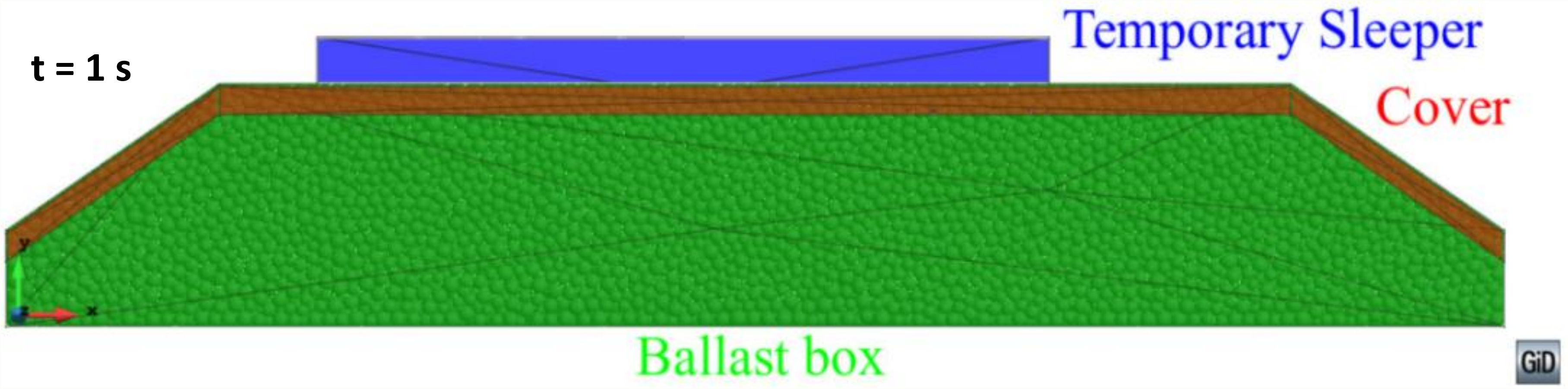
TEST RESULTS

Lateral resistance test:

t = 0 s



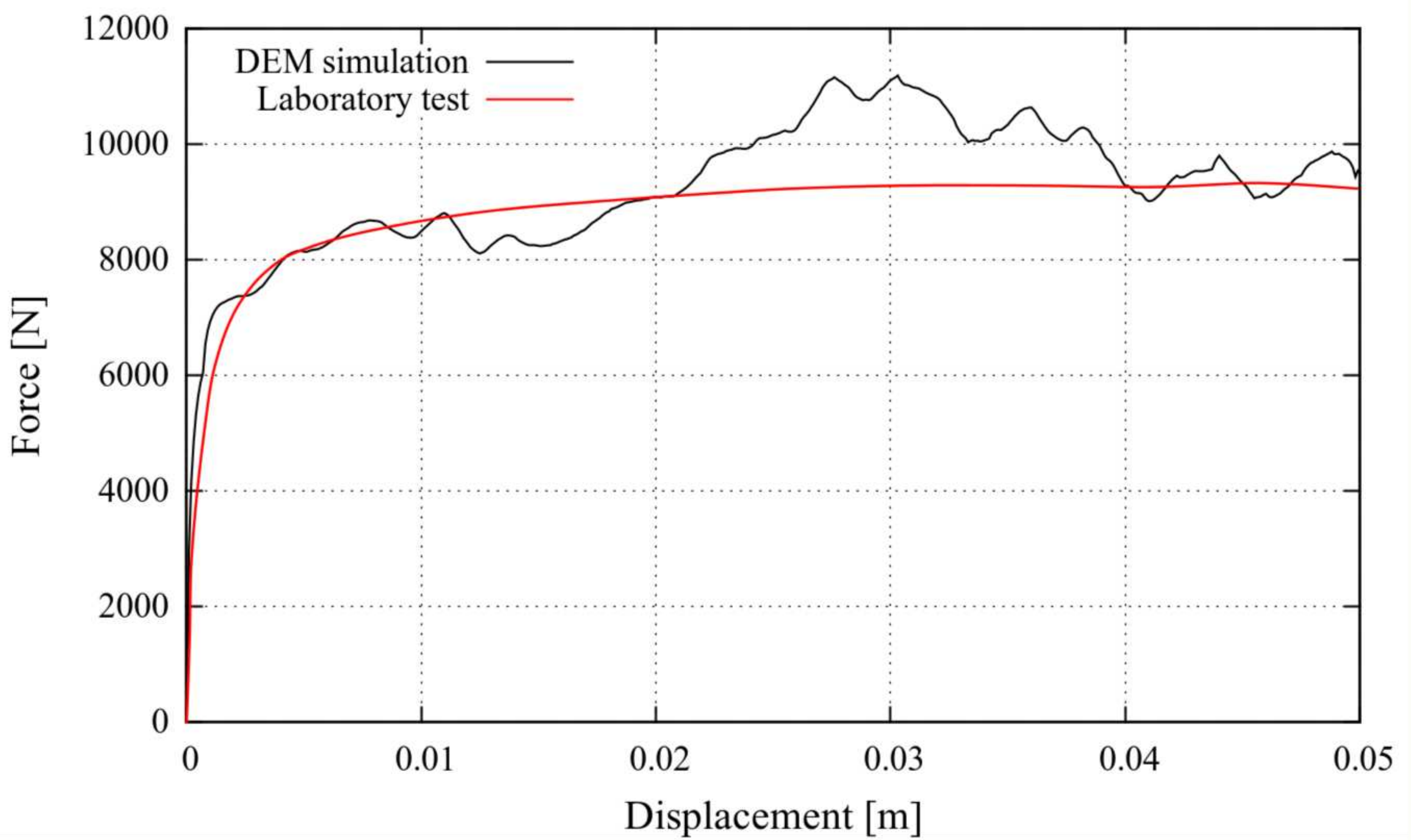
t = 1 s



CIMNE

TEST RESULTS

Lateral resistance test:

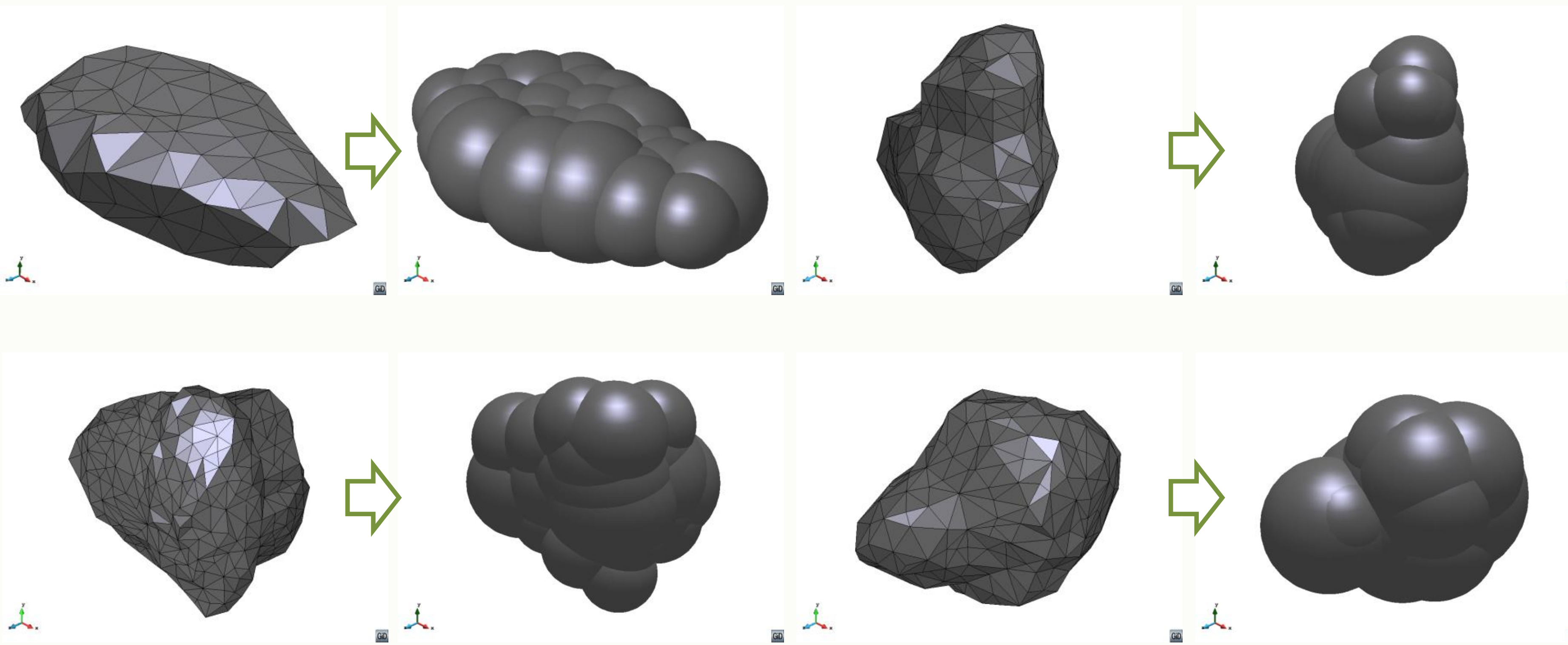


TEST RESULTS

Lateral resistance test:

DIFFERENT PARTICLES SHAPE

Sphere clusters:



Sphere-Tree Construction Toolkit (http://isg.cs.tcd.ie/spheretree/)

DIFFERENT PARTICLE SHAPES

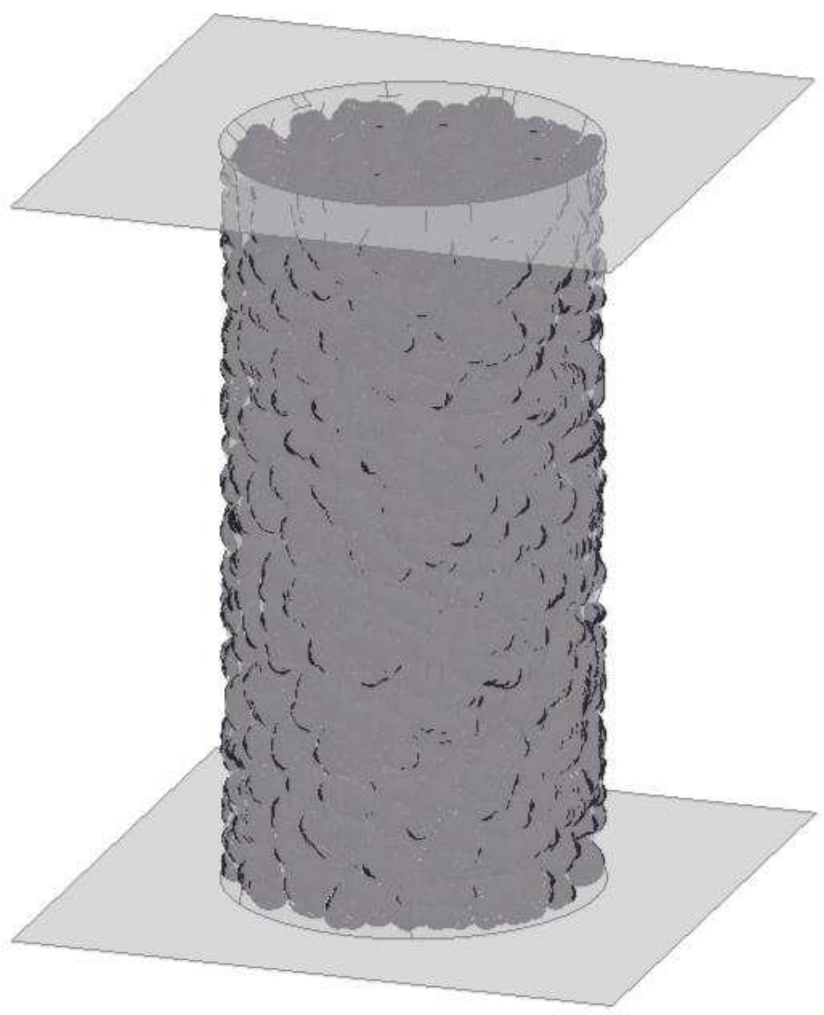
Triaxial test:

Diameter = 0.305 m
Height = 0.61 m
Confining pressure = 68.9 kPa
Shear velocity = 0.038 m/s

Quian et al. (2013) Triaxial compression test device - University of Illinois

DIFFERENT PARTICLE SHAPES

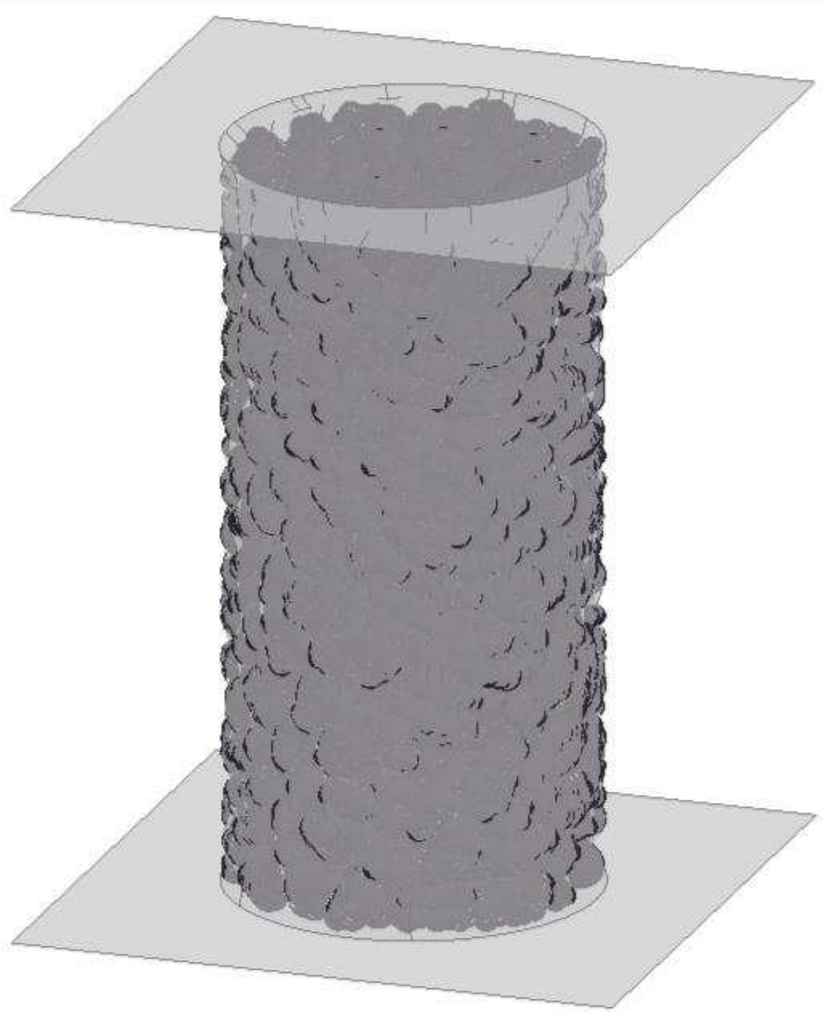
Triaxial test:



Ballast properties	
Density (kg/m^3)	2700
Young Modulus (Pa)	5.1e9
Poisson ratio	0.18
Mean diameter (m)	0.05
Friction coeff.	0.4
Friction coeff. ballast/membrane	0.0
Friction coeff. ballast/actuators	0.268
Restitution coeff.	0.4
Membrane properties	
Young Modulus (Pa)	1.5e6
Poisson ratio	0.45
Thickness (m)	0.0023
Penalty factor (γ)	100

DIFFERENT PARTICLE SHAPES

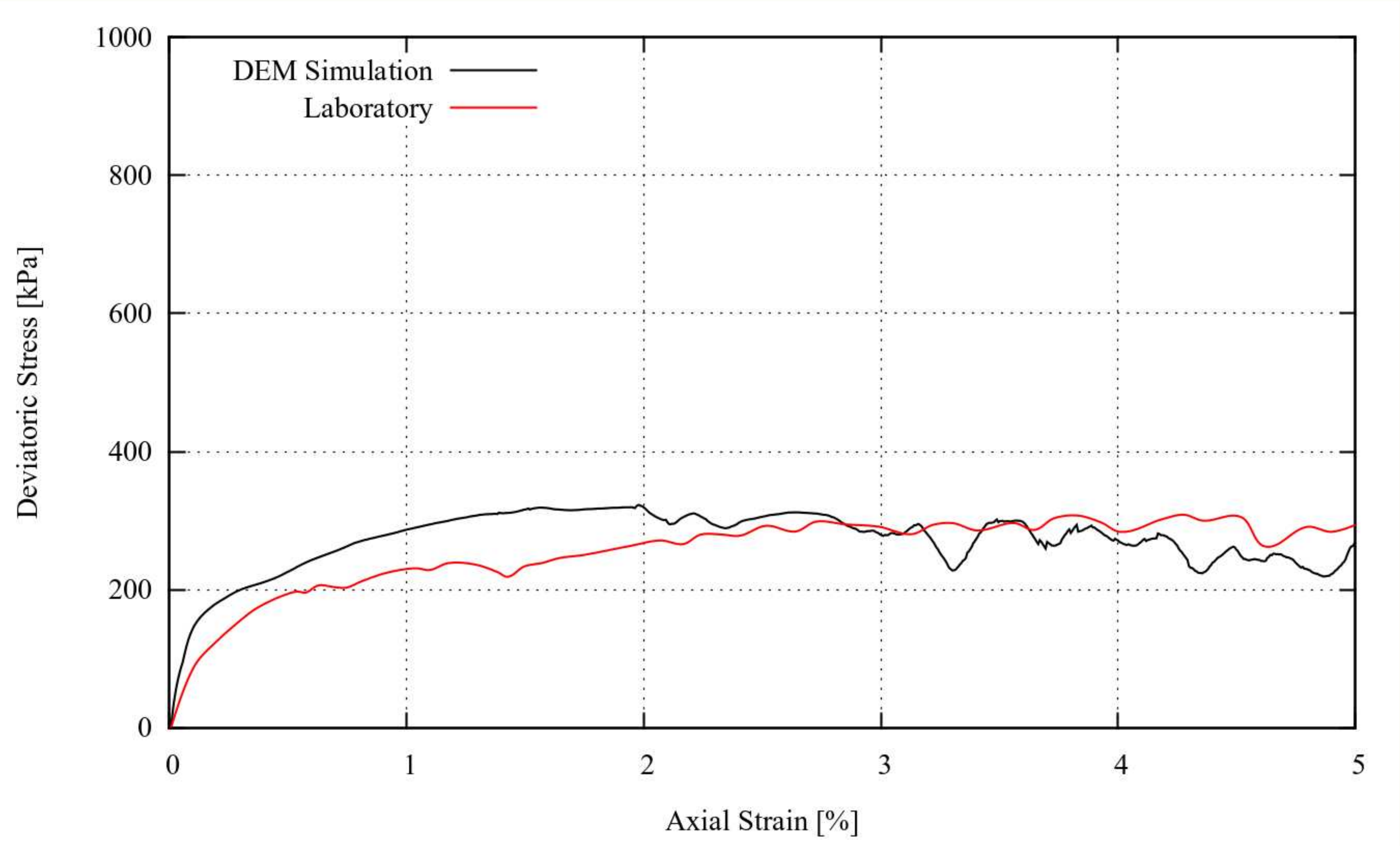
Triaxial test:



Ballast properties	
Density (kg/m^3)	2700
Young Modulus (Pa)	5.1e9
Poisson ratio	0.18
Mean diameter (m)	0.05
Friction coeff.	0.4
Friction coeff. ballast/membrane	0.0
Friction coeff. ballast/actuators	0.268
Restitution coeff.	0.4
Membrane properties	
Young Modulus (Pa)	1.5e6
Poisson ratio	0.45
Thickness (m)	0.0023
Penalty factor (γ)	100

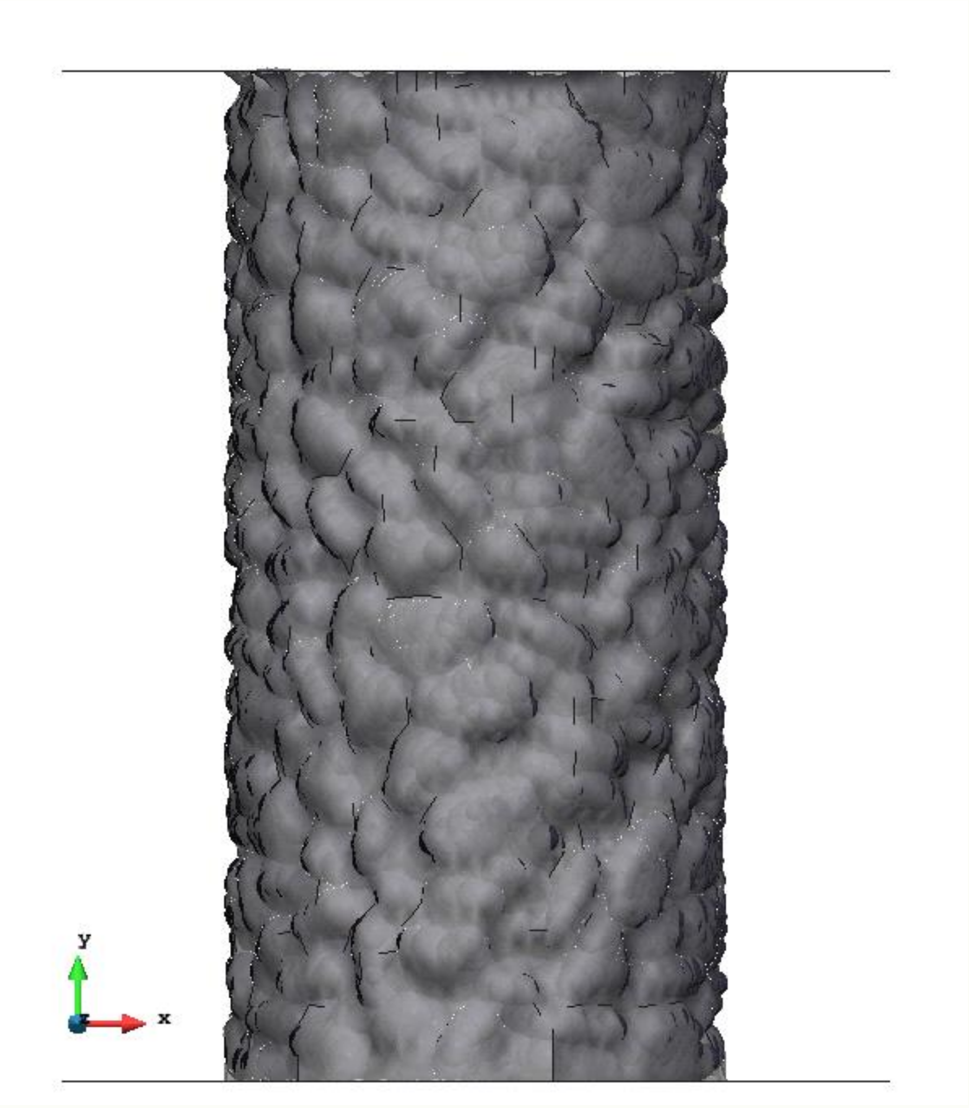
DIFFERENT PARTICLE SHAPES

Triaxial test:



DIFFERENT PARTICLE SHAPES

Triaxial test:



CONCLUSIONS

- The DEM is an appropriate method for the calculation of ballast aggregates
- Rolling friction is useful for calculations with a great amount of material
- Material stiffness is a key property when measuring deformations
- Particle packing is an important variable
- Sphere clusters are a good approach to represent real geometries with low computational cost, but more validation work should be developed

THANK YOU FOR YOUR ATTENTION

Joaquín Irazábal (jirazabal@cimne.upc.edu)
Fernando Salazar (fsalazar@cimne.upc.edu)
Eugenio Oñate (onate@cimne.upc.edu)